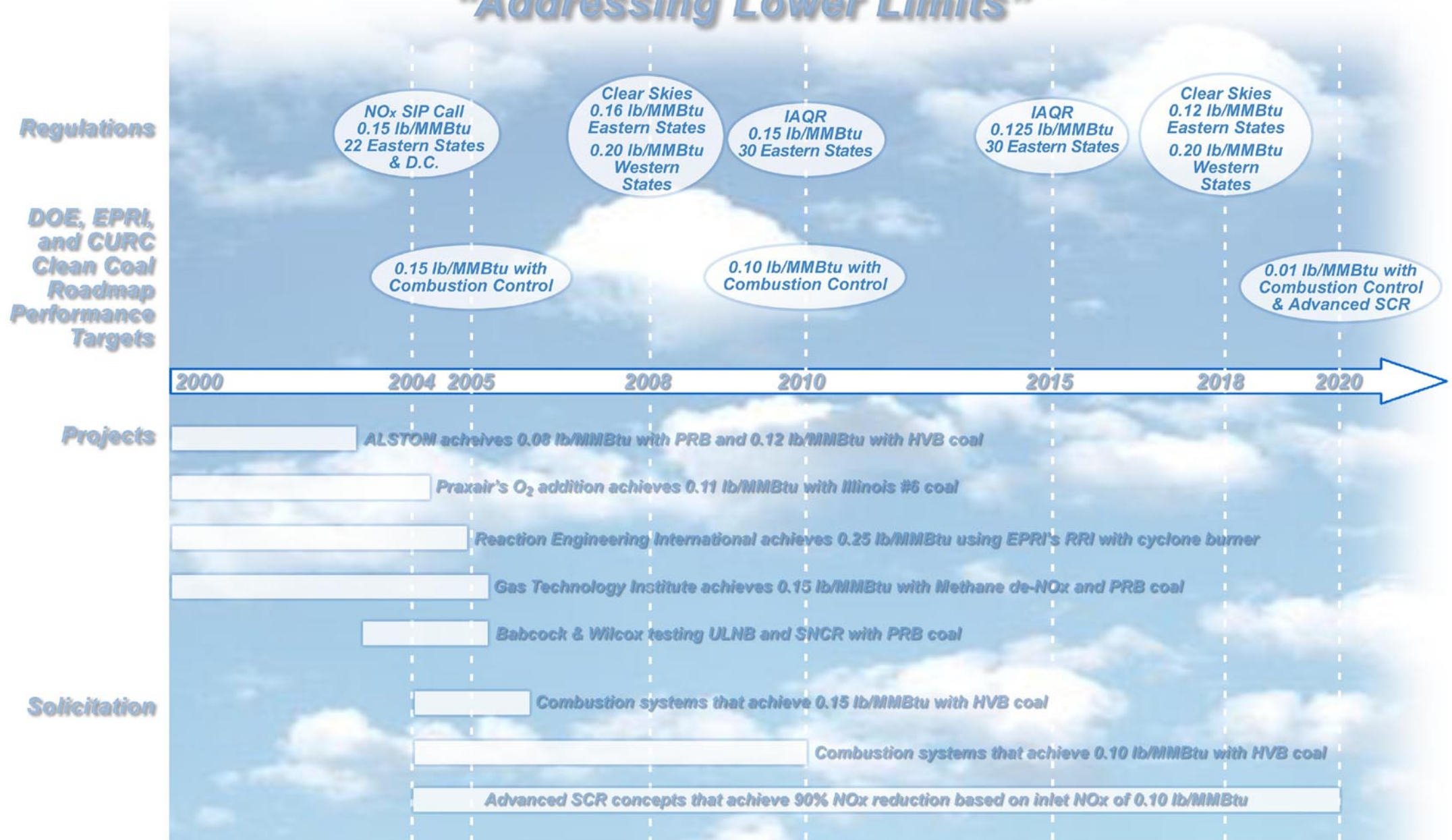


DOE/NETL's Innovations for Existing Plants NOx Control Program

"Addressing Lower Limits"



PROJECT facts

U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

OXYGEN ENHANCED COMBUSTION FOR NOX CONTROL

PRIMARY PROJECT PARTNER

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BACKGROUND

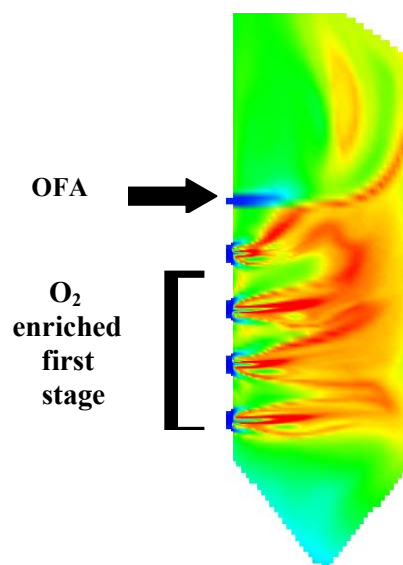
Enacted regulations pertaining to the NOx SIP Call and potential future regulations in proposed legislation such as the President's Clear Skies Initiative require power producers to seek the most cost effective methods to achieve compliance. In order to address present and anticipated NOx emissions control legislation targeting the correct fleet of U.S. coal-fired boilers, the Innovations for Existing Plants (IEP) Program develops advanced, low cost, environmental NOx control technologies for coal-based power systems. Managed by the Department of Energy's National Energy Technology Laboratory, the IEP Program develops these technologies in order to keep coal a viable part of the national energy mix. Such technologies address health and environmental visibility, eutrophication, climate change, ground-level ozone, and ambient fine particles.

As part of a Department of Energy's National Energy Technology Laboratory Cooperative Agreement, Praxair and its partners have developed an oxygen-enhanced combustion technology for controlling NOx to a level of 0.15 lb/MMBtu as well as a novel oxygen separation process to reduce the cost of oxygen production. Conventional oxygen-fired combustion has been utilized in industrial glass melting furnaces to reduce NOx emissions by as much as 80-90%. This novel technology replaces a small fraction of the combustion air. The result is a reduction in NOx emissions from nitrogen containing fuels, including pulverized coal while improving combustion characteristics such as LOI. In addressing the economic issues of oxygen production, Praxair is developing an Oxygen Transport Membrane (OTM) process that utilizes ceramic membranes with pressure as the driving force for separation of oxygen from air.

OBJECTIVES

The objective of this project is to utilize pure oxygen at a feed rate of 10% or less of the stoichiometric requirement in demonstrating the use of oxygen-enhanced combustion in meeting environmental regulations requiring NOx reductions to less than 0.15 lb/MMBtu for coal-fired boilers. Additionally, the OTM process is to produce significant quantities of oxygen from a multi-membrane reactor. In meeting these objectives, the anticipated cost of the oxygen-enhanced combustion process will cost less than 25% than the current state-of-the-art SCR installation.

Oxygen with staged combustion



DRAFT



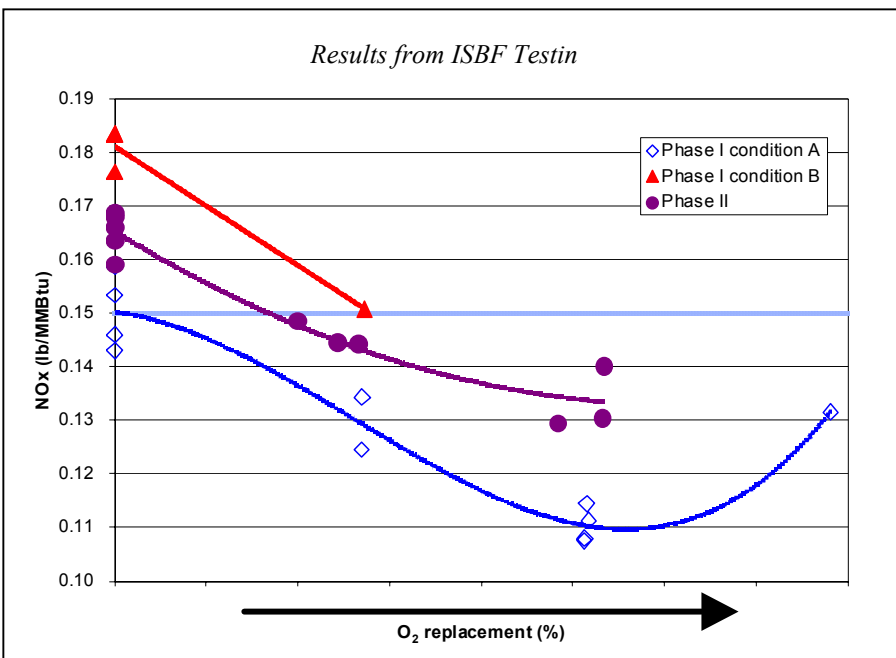
DESCRIPTION

Oxygen-fired combustion has been utilized in industrial furnaces to improve energy efficiency and reduce emissions. NO_x emissions reductions of as much as 80-90% have been demonstrated at commercial glass melting furnaces that have been converted to oxy-fuel firing. One of the required keys to successfully implementing oxygen-fired or enhanced combustion is an economical source of oxygen, which also can benefit numerous other technologies. Praxair is developing a novel oxygen separation technology at its Tonawanda, New York facility, using an Oxygen Transport Membrane (OTM).

Existing models at Praxair and REI were used to explore oxygen for coal reburning, oxygen in staged low NO_x burners (LNB), and the impact of burners on boiler operation. Praxair's novel technology to enhance coal-based reburning explored using an existing coal combustion model with full NO_x chemistry developed at Praxair. The model was used to explore the outlet gas characteristics from the device and its effectiveness as a reburn fuel.

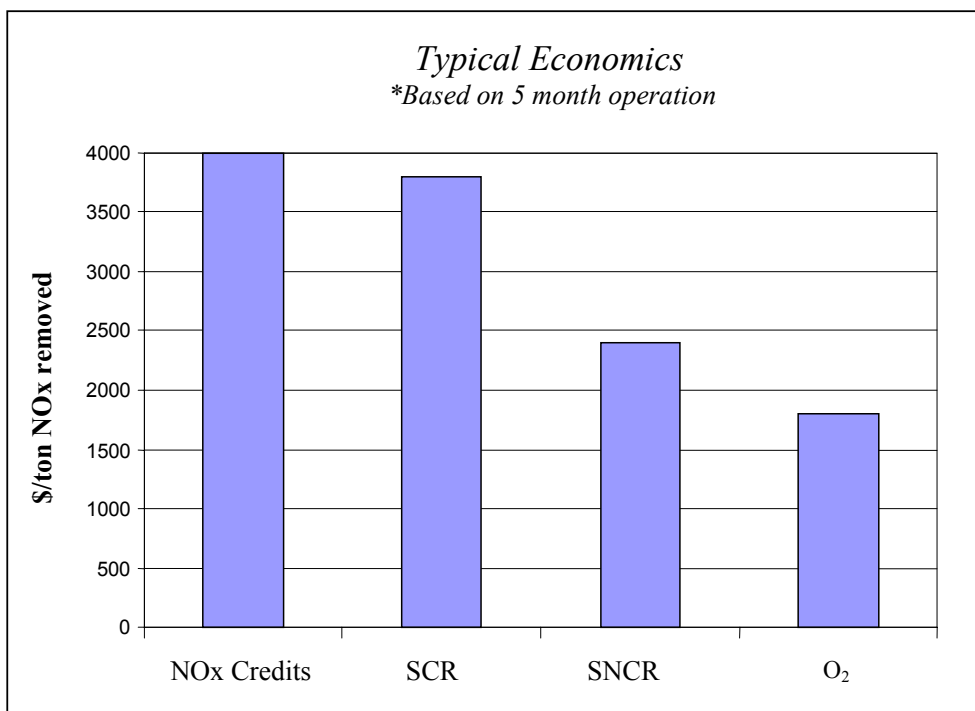
Two small combustors were used to examine the impact of oxygen enrichment on NO_x formation and on the standoff distance of coal flames. Staged combustion experiments utilized an existing 17kW downfired self-sustained combustor which provides time-temperature histories typical of full-scale utility boilers. In order to elucidate the NO_x emissions observed in these tests, experiments were performed concurrently with pilot-scale experiments.

The effect of oxygen injection on NO_x emissions from various burner types was demonstrated using a 15 MMBtu/hr pilot scale furnace designed to simulate commercial combustion conditions. Baseline NO_x data was taken for each burner type. Oxygen addition was systematically explored. Important variables were the interactions between oxygen enhancement and burner characteristics to minimize NO_x formation.



RESULTS

Almost all oxygen addition methods and replacement rates tried yielded significant reductions in NO_x emissions. Reductions in NO_x emissions ranged from 18–37%, with one condition achieving <120 ppm with small amounts of oxygen. Experiments at the University of Utah demonstrated that oxygen enhanced combustion can lead to significantly lower NO_x emissions, with some conditions leading to NO_x emissions well below the 0.15 lb/MMBtu limit even under commercially viable staging conditions. Various oxygen injection strategies were tested in the L1500, and unlike current low NO_x burners, oxygen enhanced low NO_x systems actually reduce LOI.



The membrane material element was tested in the single-tube high-pressure reactor at 900 C. The oxygen product purity was observed to be as high as 99.999% and remained above 98% for the duration of the test, which was >190 hours.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

ULTRA LOW NO_x INTEGRATED SYSTEM FOR NO_x EMISSIONS CONTROL FROM COAL-FIRED BOILERS

PRIMARY PROJECT PARTNER

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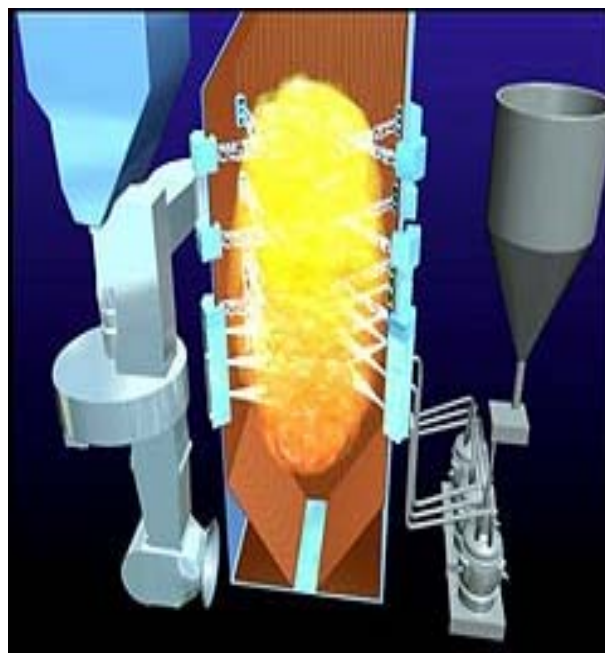
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Enacted regulations pertaining to the NO_x SIP Call and potential future regulations in proposed legislation such as the President's Clear Skies Act or EPA's Interstate Air Quality Rule require power producers to seek the most cost effective methods to achieve compliance. In order to address present and anticipated NO_x emissions control legislation targeting the current fleet of U.S. coal-fired boilers, the Department of Energy's (DOE) Innovations for Existing Plants (IEP) Program develops advanced, low cost, NO_x control technologies. Managed by the DOE's National Energy Technology Laboratory (NETL), the IEP Program develops these technologies in order to keep coal a viable part of the national energy mix. Such technologies address issues of health, ground-level ozone, ambient fine particulates, visibility, eutrophication, climate change, as well as "acid rain" precursors.

Under a cooperative agreement with NETL, ALSTOM Power, Inc. has developed an Ultra-Low NO_x Integrated System for Coal-Fired Boilers. The system enhances the performance of ALSTOM's field-proven TFS 2000™ low NO_x firing system to achieve furnace outlet NO_x emissions at or below 0.15 lb/MMBtu for existing tangentially-fired boilers firing a wide range of coals. Target NO_x emissions were obtained without increasing the level of unburned carbon in the fly ash through advances in firing technology including in-furnace combustion process modifications and a post-combustion carbon burnout technology for non-reactive coals.



OBJECTIVES

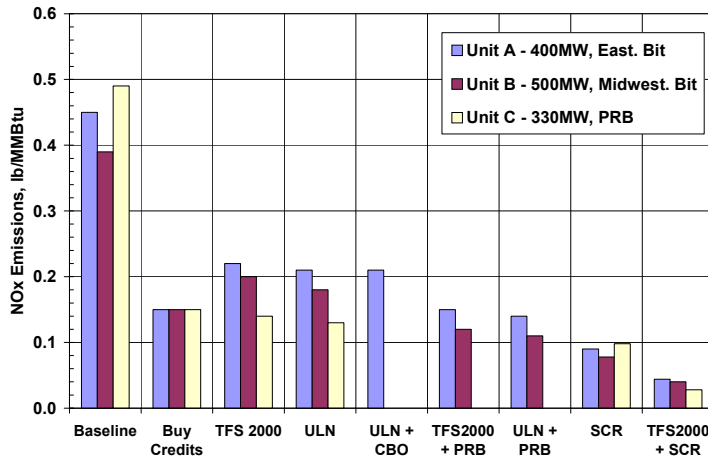
The primary project objective was to develop a retrofit NO_x control technology to achieve less than 0.15 lb/MMBtu NO_x from existing tangentially-fired utility boilers when firing Eastern bituminous coals and less than 0.10 lb/MMBtu NO_x when firing western, sub-bituminous coal from the Powder River Basin (PRB) or lignite coals. The economic project objective was to develop this technology at a cost at least 25% lower than the SCR-only technology. The NO_x control technology was to be validated through a large, 15 MW_t, pilot scale demonstration.

DESCRIPTION

The foundation for the integrated system is ALSTOM's field-proven TFS 2000™ low NOx firing system. The project plan called for the Ultra Low NOx Integrated System to improve NOx reduction over ALSTOM Power's current TFS 2000™ system through advances in several areas that overcome present constraints. The five main features of the system include the Flame Front Control Coal Nozzle Tips, Concentric Firing System (CFS™) Nozzles, Close-Coupled Overfire Air, Multi-Level Separated Overfire Air, and the Dynamic™ Classifiers.

Low NOx oxidizing pyrolysis burners, based on ALSTOM Power's LNCFS™-P2 coal nozzle tips, were designed to promote higher fuel-bound nitrogen release through more rapid heating of coal particles in the near-burner zone, coupled with the generation of additional near-burner turbulence to create a more uniform, high intensity, fuel rich zone. The low NOx oxidizing pyrolysis burners were tested in ALSTOM Power's Boiler Simulation Facility (BSF). High velocity overfire air (HVOFA) was evaluated through CFD modeling as well as through pilot-scale testing. Multiple levels of separated over-fire air (SOFA) were used to maximize NOx reductions while limiting CO emissions or increases in unburned carbon. For certain types of coal, DYNAMIC™ Classifiers were added to the pulverizers to control coal fineness and further limit unburned carbon.

For particularly unreactive coals, where higher levels of unburned carbon in the fly ash might prevent selling the ash to cement manufactures, a bubbling bed Carbon Burn Out™ (CBO) combustor, developed by Progress Materials, was evaluated as an option to reduce carbon in ash to acceptable levels. The ability to reduce the carbon content of fly ash to commercially acceptable levels coupled with the recovery of the thermal output from the CBO combustor creates an addition degree of freedom for NOx control.

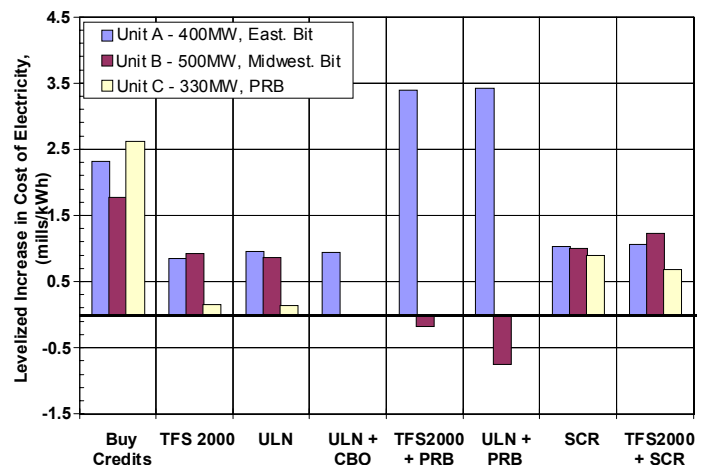


Combustion tests were performed for the three coals over the range of 30—60 MMBtu/h to quantify the impact of the proposed system improvements on NOx emissions. Baseline NOx emissions increased with coal rank 0.49, 0.56, and 0.66 lb/MMBtu for the PRB, hvb, and mvb coals, respectively. The Ultra-Low NOx firing system technology achieved NOx emissions of 0.08, 0.12, and 0.17 lb/MMBtu for the three fuels for approximately 75-85% reduction over the baseline NOx emissions.

As expected, the quantity of unburned carbon in the fly ash increased with coal rank. For the PRB fuel, the low NOx firing system technology had little impact on the unburned carbon levels that were always less than 0.1% carbon in the fly ash. In the case of the mvb coal,

unburned carbon exceeded 8% in the ash. Implementation of microfine coal grind (96% -325 mesh) reduced the unburned carbon by 50% as well as reduced the NOx emissions by 0.02 lb/MMBtu. These pilot tests demonstrate the potential of combustion-based minimization of NOx emissions. Actual performance in full scale boilers has yet to be demonstrated, but prior experience has shown performance is likely to vary due to the wide diversity of furnace geometries, operating conditions, and fuel types that exist in commercial operation today.

An engineering and economic analysis was performed for 3 tangentially-fired utility boilers in the U.S.: a 400MW unit on the East coast firing a low sulfur compliance coal (hvb), a 500MW unit in the Midwestern U.S. firing a local bituminous coal (hvb), and a 330MW unit in the Western U.S. firing a sub-bituminous coal from the PRB. The NOx reduction strategies analyzed included: buying NOx credits, TFS 2000™ firing system, Ultra-Low NOx firing system, SCR, and fuel switch to PRB coal. As might be expected, the "best" NOx reduction strategy is unit specific. The Ultra-Low NOx firing system is the recommended option for the unit firing the PRB coal as firing system modifications alone can achieve the 0.15 lb/MMBtu emissions target. Fuel switching to PRB, along with the Ultra-Low NOx firing system is the most attractive option for the Midwestern unit, while the economics for the East coast unit are very dependent upon the price of NOx credits and PRB fuel. Nineteen commercial boilers firing subbituminous coal that utilize aspects of the technologies demonstrated in this project are achieving NOx emissions at or below 0.15 lb/MMBtu.



PROJECT facts

U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

NOX CONTROL FOR UTILITY BOILER OTR COMPLIANCE

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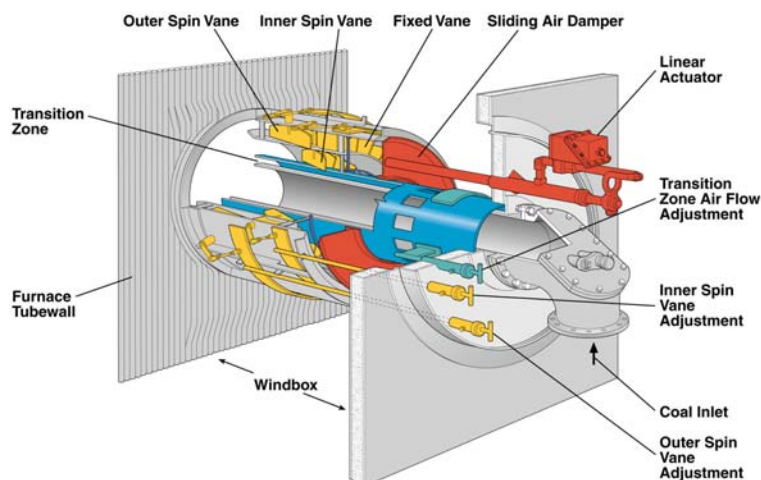
CUSTOMER SERVICE

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Under a cooperative agreement with NETL, Babcock & Wilcox (B&W) and Fuel Tech have joined in an effort to provide an integrated solution for NO_x control technology. The system is comprised of B&W's DRB-4Z™ ultra low-NO_x pulverized coal (PC) burner technology plus Fuel Tech's NO_xOut urea-based, selective non-catalytic reduction (SNCR) system. The

testing has provided insights into mechanisms that can enable SNCR technology to complement the NO_x reduction attainable with ultra low-NO_x burner technology in order to achieve NO_x emissions of 0.15 lb/10⁶ Btu for front and opposed wall-fired boilers.



OBJECTIVES

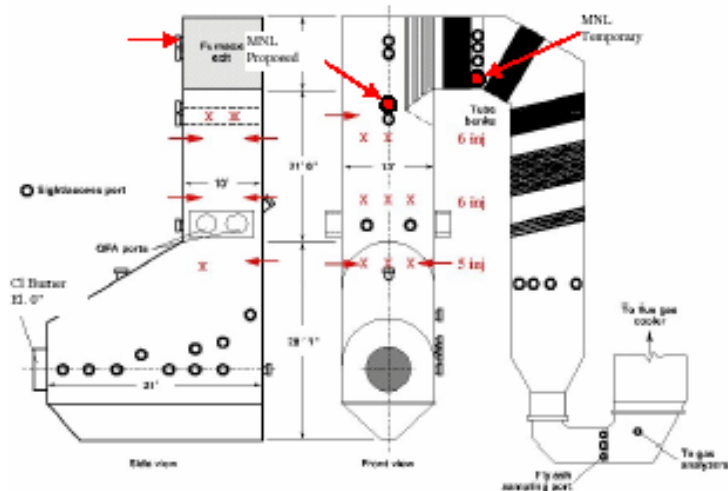
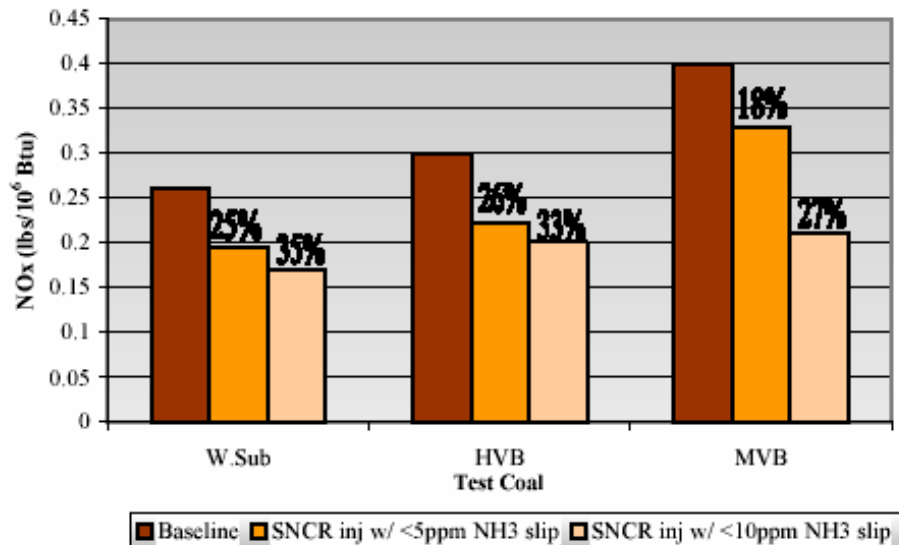
The objective of the project is to achieve a NO_x level below 0.15 lb/10⁶ Btu (with ammonia slip of less than 5 ppm) using PRB coal, B&W's DRB-4Z™ low-NO_x pulverized coal (PC) burner in combination with dual zone over fire air ports, and Fuel Tech's NO_xOUT®. The proposed goal of the combustion system (no SNCR) for this project is a NO_x level at 0.15 lb/10⁶ Btu. The NO_x reduction goal for SNCR is 25% from the low-NO_x combustion emission levels. Therefore, overall NO_x emissions could approach a level of 0.11 lb/10⁶ Btu. In addition, an SCR/SNCR hybrid technology will be evaluated using SCR at full load and SNCR at low load conditions. Since the majority of existing commercial SCR units use ammonia, SNCR data with ammonia as a NO_x reducing agent will be obtained at low load conditions.



DESCRIPTION

B&W and Fuel Tech are teaming to evaluate an integrated solution for NO_x control comprised of B&W's DRB-4Z™ low-NO_x PC burner technology and Fuel Tech's NO_xOUT®, a selective non-catalytic reduction (SNCR) technology, capable of meeting a target emission limit of 0.15 lb NO_x/10⁶ Btu. (B&W under DOE sponsorship developed and commercialized B&W's DRB-4Z™ burner.) Large-scale testing is to continue in B&W's 100-million Btu/hr Clean Environment Development Facility (CEDF) that simulates the conditions of large coal-fired utility boilers.

In a prior DOE sponsored project, three coals were tested: PRB coal, Pittsburgh #8 high volatile bituminous coal, and Middle Kittanning medium-volatile bituminous coal. Under the most challenging boiler temperatures at full load conditions, baseline (unstaged, no air staging) NO_x emissions were 0.26 lb/10⁶ Btu for PRB coal, 0.30 for Pittsburgh #8, and 0.40 for Middle Kittanning coal. The SNCR system reduced NO_x emission levels to 0.19, 0.22, and 0.32, respectively. Under the more favorable reduced load conditions, NO_x emissions were lower for both baseline (burner only) and SNCR operation. Baseline NO_x emissions of 0.17 lb/10⁶ Btu for PRB coal at 60 million Btu/hr were reduced to 0.13 lb/10⁶ Btu by SNCR. The lowest NO_x of 0.09 lb/10⁶ Btu was achieved at a 40 million Btu/hr firing rate.



The prior SNCR development work has been performed without OFA and with urea using wall-injectors. In the current project, additional baseline NO_x reductions will be achieved by the utilization of OFA. Improved performance of the SNCR process will be demonstrated with convective pass injection at full load via a convective pass multiple nozzle lance (MNL) in front of the superheater tubes. This technique has the following advantages: 1) lower injection temperature; 2) improved mixing between urea and boiler gases; and 3) achievement of very fine urea particles that evaporate quickly and engage in reducing NO_x.

The cost of the low-NO_x burner/SNCR technology is less than three-quarters of the cost of SCR. Economic analyses have shown that the total

levelized costs of low-NO_x burner/SNCR and SCR for a 500 MWe coal-fired boiler with a baseline NO_x emission of 0.5 lb/10⁶ Btu are \$406 and \$847/ton of NO_x removed, respectively.

Since SNCR performs very well in low load conditions, a hybrid SCR/SNCR technology can be commercialized to take advantage of the strength of both technologies. The full-load conditions of utility boilers are very challenging environments for SNCR technology, since temperatures are high and residence time is low for reaction. SCR, on the other hand, can achieve over 90% reduction at full load, but there are concerns about catalyst poisoning at low loads due to ammonium bisulfate deposits on the catalyst. If SNCR is used in low load and SCR in full load conditions, the hybrid system will use the strength of both technologies. Since the majority of commercial SCR units use ammonia, the current database should be expanded with testing SNCR with ammonia at low load conditions.

A hybrid SCR/SNCR system will reduce both the operating and capital costs. Operating cost savings will be realized, because when a boiler utilizes an economizer by-pass to maintain catalyst temperature, the boiler suffers an efficiency loss of up to 0.5%. Also, the operating cost will be lower since this proposed technology will prevent a potential maintenance problem with bisulfate deposits. Capital cost saving will be realized by reduction of flue work, dampers, etc., since the economizer by-pass will not be required.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Environmental and
Water Resources

Draft

METHANE DE-NOX FOR UTILITY PC BOILERS

PRIMARY PROJECT PARTNER

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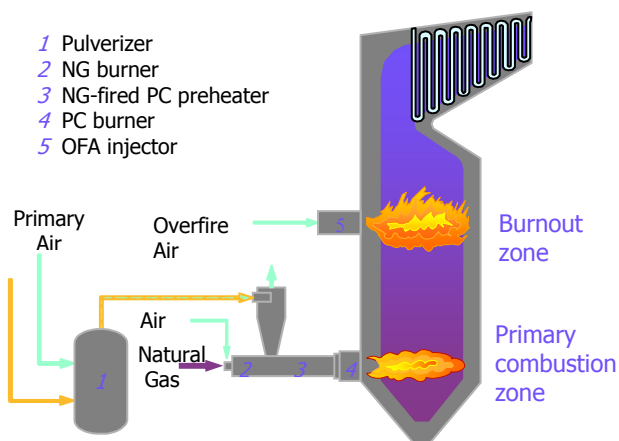
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BACKGROUND

Enacted regulations pertaining to the NO_x SIP Call and potential future regulations in proposed legislation such as the President's Clear Skies Act or EPA's Interstate Air Quality Rule require power producers to seek the most cost effective methods to achieve compliance. In order to address present and anticipated NO_x emissions control legislation targeting the current fleet of U.S. coal-fired boilers, the Department of Energy's (DOE) Innovations for Existing Plants (IEP) Program develops advanced, low cost, NO_x control technologies. Managed by the DOE's National Energy Technology Laboratory (NETL), the IEP Program develops these technologies in order to keep coal a viable part of the national energy mix. Such technologies address issues of health, ground-level ozone, ambient fine particulates, visibility, eutrophication, climate change, as well as "acid rain" precursors.

The METHANE de-NO_x[®] NO_x reduction process for PC boilers is being developed by the Gas Technology Institute (GTI) under a Cooperative Agreement with NETL to provide a cost effective, combustion-based alternative to SCR. GTI's proven METHANE de-NO_x reburn technology is combined with a pulverized coal-preheating approach developed for utility PC boilers by the All-Russian Thermal Engineering Institute (VTI). The technology consists of a burner modification that preheats pulverized coal to elevated temperatures (up to 1500°F) prior to coal combustion. This releases coal volatiles, including fuel-bound nitrogen compounds, into a controlled reducing environment inside of a natural gas-fired PC preheat combustor, which reduces the coal-derived nitrogen compounds to molecular N₂. The preheated coal is converted to a mixture of char and gaseous volatile matter, which is then fired through the main burner into the boiler furnace. The quantity of natural gas fuel required for PC preheating is in the range of 3 to 5% of the total burner heat input. GTI and VTI are joined in the project by Babcock Power Inc. (BPI), which provides commercial PC burner design expertise and testing facilities for 3- and 100-MMBtu/h preheat burner prototypes in their respective Pilot-Scale Combustion Facility (PSCF) and Coal Burner Test Facility (CBTF) in Worcester, MA.



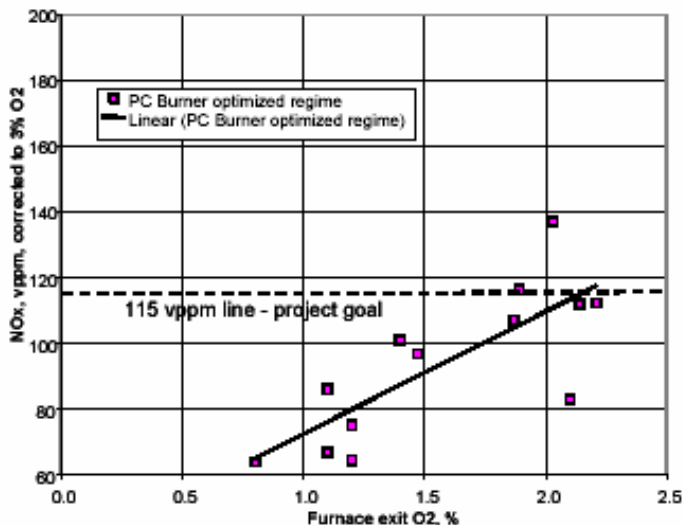
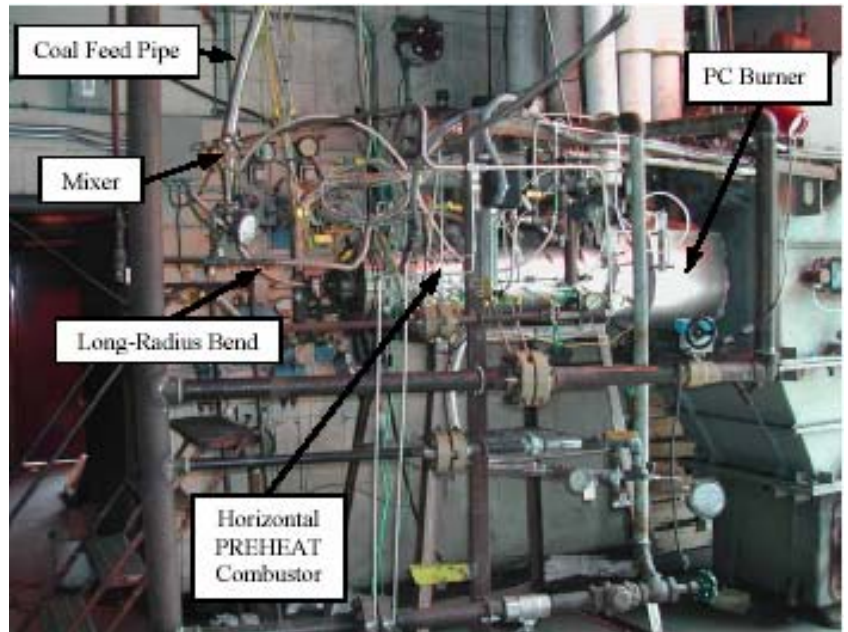
OBJECTIVES

The overall project objective is the development and validation of an innovative combustion system, based on a novel coal preheating concept prior to combustion, that can reduce NO_x emissions to 0.15 lb/million Btu or less on utility pulverized coal (PC) boilers. This NO_x reduction should be achieved without loss of boiler efficiency or operating stability, and at more than 25% lower levelized cost than state-of-the-art SCR technology.

DESCRIPTION

The advanced PC preheating combustion system being developed in this project for direct-fired PC boilers combines the modified VTI preheat burner approach with elements of GTI's successful METHANE de-NO_x technology for NO_x reduction in stoker boilers. The new PC preheating system combines several NO_x reduction strategies into an integrated system, including a novel PC burner design using natural gas-fired coal preheating, and internal and external combustion staging in the primary and secondary combustion zones.

Design, installation, shakedown and initial PRB coal testing of a 3-million Btu/h pilot system at BPI's PSCF demonstrated that the PC preheat process has a significant effect on final NO_x formation in the coal burner. Computational Fluid Dynamics (CFD) modeling was used extensively in the pilot system design for both the gas combustor and PC burner. Modifications to both the pilot system gas-fired combustor and the PC burner led to NO_x reduction with PRB coal to levels below 100 ppmv with CO in the range of 35-112 ppmv without any furnace air staging. Pilot testing with PRB coal is complete.



Initial pilot testing with a bituminous caking coal resulted in deposition and plugging by caked material on the inside of the gas combustor. A series of modifications to the combustor configuration and operation have been developed and tested. One of these approaches was successful in sustaining operation with the caking coal up to 85% of the targeted fuel input, although some deposition and LOI issues remained. Additional pilot testing is planned with the caking coal to test solutions to these problems. While not measured under steady-state operating conditions, NO_x results from the caking coal tests were promising, with NO_x levels approaching 100 ppmv with 6% oxygen in the flue gas at the furnace exit. These NO_x results indicate that even greater NO_x reduction is possible than that achieved with the PRB coal tested.

Pilot testing will be followed by design, construction and testing of a 100 MMBtu/h commercial prototype system in BPI's 29 MWt CBTF. A CFD model of the CBTF furnace will be developed and validated during the commercial prototype testing. The pilot-validated model will be used to guide the scale-up of the system. When validated through CBTF testing, the model will form a valuable design tool for future commercial installations.

The design of a 100 MMBtu/h test unit for PRB coal is complete. Fabrication and installation of the test unit has been initiated. Completion of the design for the 100 MMBtu/h preheat combustor for the caking coal is on hold pending completion of the additional pilot testing. Testing in the CBTF is scheduled for the Summer of 2004.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

PRIMARY PROJECT PARTNER

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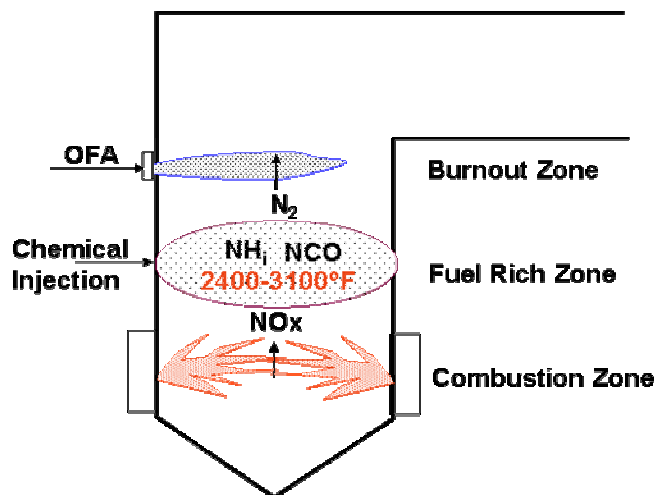


NOX CONTROL OPTIONS AND INTEGRATION FOR US COAL FIRED BOILERS (RICH REAGENT INJECTION)

BACKGROUND

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Under a cooperative agreement with NETL, Reaction Engineering International (REI) is conducting an effort to develop cost effective analysis tools and techniques for demonstrating and evaluating low NO_x control strategies and their possible impact on boiler performance for firing U.S. coals. The project addresses low NO_x issues dealing with waterwall corrosion, soot formation, ammonia on fly ash, deactivation of SCR catalysts, and the optimization of EPRI's Rich Reagent Injection (RRI) NO_x control technology which is highlighted in this fact sheet. With support from EPRI's Cyclone NO_x Control Interest Group (CNCIG), REI has developed, implemented, and tested an enhanced chemistry model with their proprietary Computational Fluid Dynamics (CFD) code *GLACIER* to simulate RRI. The concept of RRI as applied to staged cyclone fired furnaces is to use a nitrogen-containing additive to increase the NO_x reduction rate in the lower furnace.

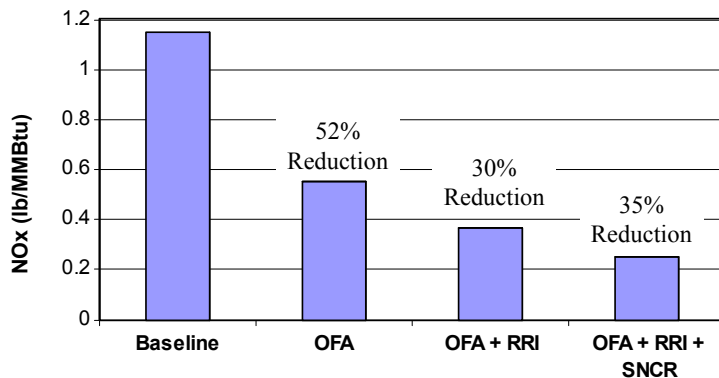


OBJECTIVES

The objective of the project is to optimize the performance of, and reduce the technical risks associated with the combined application of low NO_x firing systems and post-combustion controls that might be selected to meet targeted NO_x emissions of 0.15 lb/MMBtu and below.

DESCRIPTION

Cyclone burners create an intense flame that melts the ash to form slag. The high temperature generated by this burner results in higher uncontrolled NO_x emissions, typically exceeding 1.2 lb/MMBtu. Research has shown that the injection of ammonia (NH₃) or urea into the high temperature NO_x-containing flue gases can lead to significant noncatalytic NO_x reductions. Field-testing of RRI has been successfully completed at the commercial scale at Conectiv's 138 MW B.L. England Unit 1 and AmerenUE's 500 MW Sioux Unit 1.



At Conectiv's B.L. England Unit 1, prior installation of over fire air (OFA) and SNCR had reduced uncontrolled NO_x emissions from 1.2 lb/MMBtu to 0.35 lb/MMBtu. REI's combustion simulation software was used to design an amine-based injection system for the staged lower furnace and to evaluate NO_x reduction performance of the RRI system. Field-testing confirmed modeling predictions and demonstrated that the RRI system alone could achieve 25-30% NO_x reduction beyond OFA levels with less than 1 ppm ammonia slip and that the inclusion of SNCR could achieve an additional 35% NO_x reduction to 0.25

lb/MMBtu with less than 5 ppm NH₃ slip.

The objective of the testing at AmerenUE's Sioux Unit 1 was to determine whether similar performance could be obtained with RRI in a significantly larger unit. The field test results were found to be consistent with the CFD model predictions. Both showed that NO_x reductions of 30% from full load baseline emissions of 0.38 lb/MMBtu with OFA to 0.27 lb/MMBtu were achievable with RRI. These reductions were achieved with no predicted or measurable ammonia slip. Modeling of this unit also suggests that NO_x reductions could be improved through modification of flue gas recirculation (FGR) operation, reduction of lower furnace stoichiometry or utilization of SNCR. Although the target emissions of 0.15 lb/MMBtu were ambitious for this style of burner, these results are substantial when compared to the Title IV NO_x limit of 0.86 lb/MMBtu for cyclone-fired boilers. These units, which account for only 8% of the U.S. generating capacity, emit nearly 20% of the coal-fired NO_x emissions.

